SWITCHING NETWORK

This invention relates to a switching network for switching signals between inputs and outputs.

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The invention particularly relates to switching networks forming part of digital cross-connects. Referring to Figure 1, such digital cross-connects typically comprise a series of input modules A, a series of output modules B, and a switching network C linking them. The input modules receive, on various inputs, data streams in formats such as

10   synchronous digital hierarchy (SDH), synchronous optical network (SONET), or optical transport network (OTN) format, and process those data streams (for example, detect and remove maintenance and signalling information), to create internal frames which are passed to the switching network C. Switching network C then routes the internal frames to the appropriate output, and the output modules B build the outgoing data

15   streams eg SDH, SONET or OTN, by adding maintenance and signalling information.

A matrix-controller unit D forms part of the switching network C and is in charge of controlling switching behaviour and implementing the routing algorithm.

20   One known network for switching any of n inputs to any of m outputs is a multi-stage network that uses at least one intermediate stage to reduce the number of cross-points without increasing blocking, and is known as a Clos network after the technical paper published by Charles Clos in 1953.

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A typical known Clos switching network is shown in Figure 2. The first stage 1 has "a" switching matrices, each having "b" inputs and "c" outputs. The intermediate stage 2 has "c" switching matrices, each having "a" inputs and "a" outputs, and the output stage 3 has "a" switching matrices, each having "c" inputs and "b" outputs.

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The outputs of each first stage 1 matrix are connected to the inputs of all the intermediate stage 2 matrices by only one link, and the outputs of each intermediate stage 2 matrix are connected to the inputs of all the output stage 3 matrices by only one link.

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The fraction c/b is called the expansion factor, and is related to the number of matrix internal paths and therefore with the probability of finding a route from input to output of the switching network. If the term "b" equals or exceeds twice the term "a" minus 1, which approximates to the expansion factor being greater than or equal to 2, according

15   to the theory of Clos switching networks it is possible to fill completely the outputs of the networks by always finding a path connecting any input with any output.

This invention is concerned with Clos switching networks, in which the expansion factor is less than 2 (it must be greater than unity, or a blocking situation could exist

20   inside a single switching matrix), in order to provide an increased capacity by increasing the number of inputs and outputs, without unduly increasing the cost. However, this increases the risk of failing to find a path through the network, and makes it necessary to use a complex traffic status re-arrangement algorithm.

An example of how blocking could occur with an expansion ratio of less than 2 is illustrated with reference to Figure 3, which shows a three-stage Clos network having nine matrices in each stage, although only one matrix is shown on the input and output stages. Each of the matrices on the input stage 4 has eight inputs by nine outputs, each

5   on the intermediate stage 5 has nine inputs by nine outputs, and each on the output stage 6 has nine inputs by eight outputs. The expansion ratio is thus 9/8.

Consider an attempt to make a cross-connection between input 1 of the first matrix on the input stage 4 and output 1 on the first matrix of the output stage 6. Suppose that

10   outputs 2 to 8 of the latter are used and fed by connections coming from the intermediate stage 5 matrices 3 to 9. Therefore the cross-connection can only be made only via intermediate stage 5 matrices 1 and 2, from the first matrix of the first stage 4. However, if outputs 1 and 2 of the first matrix of the input stage 4 (which connect to the first two matrices of the middle stage) are used by two connections going to any output

15   stage matrix 8 apart from the first, the intended cross-connection cannot be made.

The invention is concerned with switching data frames at the different traffic levels defined by various digital standards, such as the SDH, the SONET or the OTN standard. Referring to Figure 4, the basic SDH multiplexing structure is illustrated

20   (Recommendation ITU-G.70X). The x3 on the link between the AU(Administrative Unit)-3 and AUG data frames indicates that the AUG data frame incorporates three AU-3 data frames. An STM (Synchronous Transport Module)-N frame may incorporate one AUG frame when N=1, and, say, 16 when N=16. Data frames are typically transmitted

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at 8000 frames per second, so the data rate for the larger frames is proportionately
greater. The data rate for an STM-16 data frame is approximately equal to 2.5Gbit/sec.

The input, output and internal links of the Clos network shown in Figure 2 may thus

5   accommodate a predetermined number of time slots, for example, 48 time slots
corresponding to a 2.5Gbit/sec. data rate. Each slot is always filled with stuffing or with
valid data, in the last case, data that comes from a particular input to the switching
network. A time slot can thus belong to any type of traffic. For example, it could be a
third of a STM-1, a twelfth of a STM-4 etc., or may be unused, that is to say, filled with

10   stuffing that is produced by the switching network itself.

It is known for such a Clos network to permit time division multiplexing (TDM) of data
in its internal links, in addition to its space routing capability. Referring to Figure 5,
given a particular element 7 on input "x" of any particular switching matrix of the

15   network of Figure 2, the switching matrix 4 can move it to output "y" (space routing)
and, inside the "y" stream, to a new time position (time-multiplexing).

The Applicants examined typical blocking situations in a Clos network switching digital
data, and noted a good deal of fragmentation in the data filling the internal links. For

20   example, some of the connection requests coming into the switching network were at a
low data rate, such as STM-1, in which case three of the 48 time slots in the above
example would be filled by valid data, and 45 would be filled by stuffing, leaving the
links largely free but nevertheless unable to host another request, perhaps for STM-16.

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The invention provides a switching network for switching frames of data, in defined

time-slots, of a cross-connection request between a desired input and a desired output,

comprising an input stage consisting of a plurality of switching matrices, an

intermediate stage consisting of a plurality of switching matrices, and an output stage

5   consisting of a plurality of switching matrices, each input stage switching matrix having

a link to each intermediate stage switching matrix and each intermediate stage switching

matrix having a link to each output stage switching matrix, including means for routing

each time-slot of each frame independently through the switching matrices.

10   This permits better utilisation of internal links and correspondingly reduced blocking.

Advantageously, the expansion ratio (of outputs to inputs of the input stage switching

matrices) is less than two, preferably less than 1.25 which would previously have been

prone to Clos blocking.

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Advantageously, the switching matrices have time division multiplex links. Each time

slot may accommodate one frame whose nominal data rate is at least one sixteenth,

preferably at least one forty-eighth, of the data rate of the links.

20   A switching matrix for switching frames of data, constructed in accordance with the

invention, will now be described in detail, by way of example, with reference to the

accompanying drawings, in which:

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Figure 1 is a block diagram showing a digital cross-connect incorporating a switching network, both as known, and in accordance with the invention;

Figure 2 is a block diagram of a three-stage Clos switching network, both as known, and

5   in accordance with the invention;

Figure 3 is a block diagram of part of a particular example of a known Clos switching network showing a blocking situation;

10   Figure 4 is a diagram illustrating the structure of an STM SDH data frame;

Figure 5 is a block diagram depicting a switching operation of a switching matrix of the Clos switching network of Figure 2;

15   Figure 6 is a block diagram depicting an example of the internal filling of a three-stage Clos switching network in accordance with the invention;

Figures 7A to 7I are diagrams showing the filling of the links to the intermediate stage switching matrices, and Figure 7J is a diagram showing the filling of the links to the

20   input stage switching matrices;

Figure 8 is a flow-chart depicting the method of internal filling of the three-stage Clos network of Figure 6;

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Figure 9 is a block diagram of a further example of the internal filling of a three-stage Clos network in accordance with the invention;

Figure 10 is a block diagram showing the splitting and recombination of a data frame

5   entering and leaving a three-stage Clos switching network in accordance with the invention;

Figure 11 is a block diagram showing a further example of internal filling of a three-stage Clos network in accordance with the invention; and

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Figure 12 is a flow-chart depicting a re-arrangement algorithm.

Referring to Figure 1, the switching network of the invention forms part of a digital cross-connect and, as with conventional cross-connects, includes a series of input

15   modules A and output modules B, which remove and restore, respectively, maintenance and signalling information, to create internal frames which are routed through the switching network C. The internal frames are generated by the input modules A by replacing some bytes of the incoming SDH, SONET or OTN frames with information used by the switching network C or with stuffing. The removed bytes carry signalling

20   information. The output modules B effect the inverse process : they replace those internally used bytes of the internal frame with information belonging to SDH, SONET or OTN standards.

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The switching network of the invention also includes a matrix-controller unit D to control the switching behaviour and implement the routing algorithm in accordance with the invention.

5   Referring to Figure 6, the switching network of the invention will be described with reference to a three-stage Clos network receiving incoming traffic according to the SDH standard, in which there are 36 switching matrices in each of the input 9, intermediate 10, and output 11 stages. Those in the input stage have 32 inputs by 36 outputs, those in the intermediate stage have 36 inputs by 36 outputs, and those in the output stage have

10   36 inputs by 32 outputs. As with a conventional Clos network, each input stage 9 switching matrix has one, and only one, link, indicated generally by the reference 12, to each intermediate stage 10 switching matrix, and each intermediate stage 10 switching matrix has one, and only one, link, indicated generally by the reference 13, to each output stage 11 switching matrix. Links to the input and output of the switching network

15   are indicated generally by the reference numerals 14,15.

The switching network is such that traffic travels from any input stage switching matrix to any intermediate stage switching matrix, and from any intermediate stage switching matrix to any output stage switching matrix, on a 2.5Gbit/sec physical link .The signal

20   on the links 12,13,14,15 is a Time Division Multiplexed signal made of 48 time slots. Each time slot has a bit rate of 2.5Gbit/sec/48. This speed rate is the bit rate of an AU-3 type signal. Each slot is filled with stuffing, generated by the switching network, or valid data, which can be an entire AU-3 frame, a third of an STM-1 frame, a twelfth of an STM-4 frame, or a forty-eighth of an STM-16 frame.

Input to the switching network is in form of data frames at the different traffic levels
according to the SDH standard. Each input link can accommodate all data frames equal
or lower in bit rate to STM-16, that is to say, VC3, VC4, STM-1, STM-4, STM-16.

5   Data frames of higher bit rate are accommodated on more input links. For example, an
STM-64 is placed on four input links.

The switching network would be prone to blocking for such traffic if the frames were
routed as whole frames as in known switching network as in Figures 1 and 2, because

10   the expansion ratio of the input stage switching matrices 9 is 9/8, considerably less than
the Clos non-blocking expansion ratio of approximately 2.

In accordance with the invention, the matrix-controller unit D includes means for
routing each time-slot of each frame independently through the switching matrices.

15   Thus, referring to Figure 8, when a user makes a cross-connection request, the request is
split into AU-3 lower data rate streams consisting of individual time slots, each
containing an AU-3 frame.

The next step performed by the matrix-controller unit D of the invention is the creation

20   of a list of intermediate stage switching matrices, showing the occupation of the links,
firstly, from the input switching matrix at which the request originated and, secondly, to
the particular output switching matrix containing the requested output. The list is sorted,
firstly, on the basis of the occupation of the links 13 between the intermediate stage
switching matrices and the particular output stage switching matrix requested, the

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matrices corresponding to the links which have most time-slots free of valid data being first. If there is more than one link with an equal number of free time-slots, then the respective switching matrices are sorted, secondly, on the basis of the number of free time-slots in the links 12 to the input stage switching matrix at which the user cross-

5   .connection request was received. If there is more than one intermediate stage switching matrix with an equal number of free time-slots in the links 12, and an equal number of free time-slots in the links 13, for example, when all time-slots are free of valid data, then the switching matrices are listed on the basis of numerical order as seen in Figure 6, or in some other predetermined order.

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In the case of a request for a mono-directional connection, time-slots are allocated in the links 12,13 of the first intermediate stage switching matrix in the list, for the first AU-3 time-slot of the cross-connection request. Time-slots in the links 12,13 of the next intermediate stage switching matrix in the list are then allocated for the next AU-3 slot

15   of the cross-connection request, and so on. Each time-slot is handled separately using the same algorithm.

A specific example is now given with reference to Figure 6. Assume that there is no cross-connection across the switching network, so that all links 12,13 each have 48 time

20   slots filled with stuffing. Assume further that a mono-directional connection for an STM-16 data frame from 40th input to 300th output is required. This means that it is necessary to interconnect the 8th input on the 2nd input stage switching matrix with the 12th output of the 10th output stage switching matrix.

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The STM-16 connection request is dealt with as if it were 48 independent AU-3 mono-directional connection requests. Referring to Figure 7A, the 36 columns relate to the intermediate stage switching matrices. The first row (Clos) is the number of the intermediate stage switching matrix, the second row is the AU-3 filling of the link

5   between the specified intermediate stage switching matrix and the output stage switching matrix required, and the third row is the AU-3 filling of the link between the input stage switching matrix at which the request originated and the specified intermediate stage switching matrix. The AU-3 filling can be any number between 0 and 48. The algorithm creates such a list for any required connection.

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The situation before the request is shown in Figure 7A. The situation after having routed the first AU-3 is shown in Figure 7B. The situation after having routed the second AU-3 is shown in Figure 7C. After 36 AU-3 have been routed, all intermediate stage switching matrices (Clos) again have the same priority, as shown in Figure 7D. After

15   the last AU-3 has been routed, the ordered list is as shown in Figure 7E.

A representation of this internal filling of the intermediate stage switching matrices is shown in Figure 6. Any further request not involving the 2nd input stage switching matrix and the 10th output stage switching matrix will be routed in the same way.

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Consider now a mono-directional connection from 5^{-th} VC(Virtual Container)-4 frame of 700^{-th} input to 2^{-nd} VC-4 of 307^{-th} output where the output stage switching matrix is the same as that of the previous request. From the switching network point of view this means that the 13, 14 and 15 AU-3 time slots of 28th input of 22nd input stage switching

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matrix must be connected to the 4, 5 and 6 AU-3 time-slots of the 19th output of 10th

output stage stage switching matrix. The algorithm will deal this VC-4 connection like 3

independent AU-3 mono-directional connections.

5   The situation before the request is as shown in Figure 7F. This list takes into account

(see row 2 "Out") the filling of the links 13 resulting from the first connection. After the

last AU-3, the ordered list is as shown in Figure 7G. This new internal filling is shown

in Figure 9.

10   The internal links 12, 13 are TDM links with 48 slots available for data. The

individually-routed AU-3s will normally be fed to the first free slot in the respective

link, irrespective of the position along the 48 slots. Thus, one particular AU-3 could be

accommodated in the first TDM slot of one link. The next AU-3 could be

accommodated in the last TDM slot of the next link used, and a third AU-3 could be

15   accommodated in a slot intermediate the ends of the row of 48 time-slots. The important

thing is that the AU-3s are collected in order at the output of the respective output stage

switching matrix.

Referring to Figure 10, consider the routing of a VC4 frame (3 time slots equivalent to

20   a repetitive sequence of three AU-3 bytes "a,b,c"). Matrix-controller unit D configures

the input stage, intermediate stage and output stage Clos blocks in the way shown in the

Figure. Busy time-slots, corresponding to other user requests, are denoted "x". The

sequence of incoming bytes "a,b,c" is split on the input stage such that byte "a" goes to

intermediate stage switching matrix i, byte "b" goes to intermediate stage switching

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matrix j, etc. The capability of every switching matrix to route a byte incoming on any time slot of a link to any time slot of any outgoing link is used. Byte "a" is carried within time slot 2 in links 12 and in time slot 47 in links 13, and so on for bytes "b" and "c". It is the respective output stage switching matrix stage 11 which maps again the

5   correct VC4 structure by ordering "a,b,c" bytes in their correct order.

Among the key features of the switching network of the invention described above are: time-multiplexing (which is made possible by the switching matrix hardware); and the possibility of splitting any SONET, SDH or OTN traffic into AU-3 data stream level.

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Input traffic to switching matrix can be seen as a set of AU-3 data frames no matter the real input traffic level to the digital cross-connect (for example, STM-1, STM-4, STM-16, etc. from SDH equipment, and STS-1, STS-3, etc. from SONET equipment).

15   All AU3 slots are routed in an independent way balancing the filling of intermediate stage switching matrices, first towards the outputs from the intermediate stage and second towards the inputs to the intermediate stage. This reduces or eliminates fragmentation because none of the links 12,13 is filled completely (i.e. not all time slots filled) before input/output saturation is reached.

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Given a particular output stage switching matrix to be reached to satisfy a customer request, the algorithm chooses the intermediate stage switching matrices to use by balancing the filling (measured in number of time slots 0 to 48) of the links between them and that particular output stage switching matrix. Returning to the example above

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given with reference to Figure 9, after having placed the second request – the VC4 – a

successive request , at any traffic level VC4 to STM256, that needs to reach output

stage switching matrix no.10 will not use intermediate stage switching matrices nos.1, 2,

3, 25, 26, 27 , 28 , 29, …., 36 because the filling of their link to the output stage

5   switching matrix no. 10 is equal to 2 , and instead intermediate stage switching matrices

nos. 4,5,6,….,24 will be considered first since the filling of their link to the output stage

switching matrix no. 10 is equal to 1.

Referring back to Figure 8, a request for a broadcast connection, that is, a connection

10   from an input to more than one output, is dealt with differently to a request for a mono-

directional connection, that is, a request from one input to one output. In the case of the

former, if there are already connections in place across the switching network relating to

the broadcast request using the same output stage switching matrix, the connection is

only routed in the output stage switching matrix which already carries the broadcast

15   request. An input on such an output stage switching matrix is connected to two or more

outputs instead of only one.

If there are not such connections in place using the same output stage switching matrix,

the algorithm looks for intermediate stage switching matrices already used to route a

20   previous branch of the same broadcast. If there are such intermediate stage switching

matrices, the algorithm chooses between them based on the priority list referred to

above, again, by connecting the inputs to those matrices to multiple outputs. If there are

no such intermediate stage switching matrices in use, there is used the first path of the

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priority list that satisfies the request that the links 12 (input to intermediate) and 13
(intermediate to output) are free.

To take an example, suppose the VC-4 shown in Figure 9 (5^{-th} VC-4 of 700^{-th} input) also
5   requires to be connected to the 14^{-th} VC-4 of 1137^{-th} output, changing a mono-
directional connection to a broadcast connection. This is illustrated in Figure 11. This
new branch is not on the same output stage switching matrix (it is on 36th not 10th
stage), so the same output switching matrix cannot be used. As before, the 13, 14 and 15
AU-3 of 28th input of 22nd input stage switching matrix have to be connected, this time
10   to the 40, 41 and 42 AU-3 of the 27th output of 36th output stage switching matrix. As
usual the algorithm will deal this VC-4 connection like 3 independent AU-3
connections.

The situation before the request for the additional connection required is shown in
15   Figure 7H. It should be noted that for each AU-3 there is already a path from the input
to the intermediate stage due to the previous branch from the 5th VC-4 of 700th input
(intermediate stage switching matrices 1-3), so the second branch on the intermediate
stage can be opened simply by programming further links 13 from those switching
matrices. When the last AU-3 is routed, the ordered list is as shown in Figure 7I. Note
20   that if the additional requested outgoing stream was on 10th output stage switching
matrix (outputs in the range: 289 – 320), the algorithm would have created the broadcast
connection on the 10th output stage switching matrix.

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A computer simulation of the above described routing algorithm, has shown no

blocking situation, and therefore no need to re-arrange. It is believed that the reason for

this is the splitting of data traffic into AU-3 structures.

5   However, it is envisaged that blocking could take place in the event of hardware failure,

such as of intermediate stage switching matrices. The algorithm does therefore include a

re-arrangement strategy which takes account of just this situation.

Re-arrangement is a method of changing the internal matrix occupation while

10   preserving the input/output status. One of the purposes is to produce a new internal

status more suited than the old one to accommodate new paths; another is to reallocate

internal paths avoiding intermediate stage switching matrices out of order. Re-

arrangement is therefore an intelligent sequence, according to some strategy, of

provisioning requests. Note that normal provisioning, driven by the customer, is, of

15   course, a random sequence of provisioning requests.

Many different re-arrangement strategies were simulated all of them using the routing

method before described, and all of them worked. To discriminate among them inputs

32 to 36 of the input stage switching matrices were considered. The re-arrangement

20   strategies failed, but the one that was selected showed a better behaviour in terms of

number of block situations solved.

The re-arrangement algorithm works as follows, referring to Figure 12.

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First every n-branch broadcast connection (only for broadcast connections which open on the input or intermediate stages) is considered as a series of n-mono-directional connections. Then every AU-3 component of each cross-connection is considered.

5   It is now necessary to determine which input stage switching matrix to start with for re-arrangement. For each input stage stage switching matrix, the sum of outgoing AU-3s in use is calculated. A list of such matrices ordered according to this sum is calculated in descending order. If there is more then one input stage switching matrix with the same value, they are ordered by considering the sum of incoming AU-3 components in use in

10   descending order.

Taking the first element of the list, all mono-directional connections (of this input stage switching matrix) are re-routed starting from the lowest input (using the normal routing algorithm). All broadcast connections (of this input stage switching matrix) are re-

15   routed starting from the lowest input (using a modified routing algorithm). The modified routing algorithm chooses, first, the intermediate stage switching matrix that can accept the highest number of broadcast branches. If there are many such switching matrices, they are discriminated by taking in account the one with a lowest number of AU-3 in use. This operation is repeated until all the broadcast branches have been

20   placed.

A specific re-arrangement example is now given. It is assumed that the input/output status is as follows:

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STM-16 mono-directional connection from 40th input to 300th output; VC-4 broadcast

connection from 5th VC-4 of 700th input to 2nd VC-4 of 307th output and to 14th VC-4

of 1137th output (as illustrated in Figure 11); and, in addition, VC-4 mono-directional

connection from 9th VC-4 of 390th input to 2nd VC-4 of 50th output.

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The list showing input stage switching matrix output and input link AU-3 filling will be

as shown in Figure 7J. Switching matrix number 2 is considered first, and its mono-

directional connection is re-routed (there is no broadcast connection). The next input

stage switching matrix to be considered is number 22. There is no mono-directional

10   connection so the two branches of the broadcast connection are re-routed. The last input

stage switching matrix is number 13 where the mono-directional connection is routed.

Variations may be made without departing from the scope of the invention. Thus,

instead of having a single intermediate stage between input and output stages, more than

15   one, for example, three stages may be included between the input and output stages.